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FOUNDATION CORROSION SURVEY CIRCUIT L22H (EASTERN REGION) PRELIMINARY REPORT

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A corrosion survey of transmission tower footings was undertaken along a portion of circuit L22H, a 230 kV transmission line in Eastern Region. The survey included measurements of leg-to-soil potentials and corrosion currents using a Tower Leg Integrity Monitor (TLIM 100). Soil samples were taken for laboratory measurements of soil resistivity, pH and sulphur content. Current readings on sacrificial anode systems were also made using a clip on ammeter. It is concluded that both circuit and potential measurements will give a more complete picture of underground corrosion activity and that the TLIM 100 is a simple instrument to use on a routine basis. The measurement of specific soil parameters in the laboratory help identify certain soil conditions which may promote corrosion activity, but to date these parameters do not exhibit good correlation with in situ electrical measurements.

1.0 INTRODUCTION

The corrosion survey is a routine maintenance activity which is conducted to help determine the condition of metal in galvanized steel, transmission tower legs. The deterioration of metal through corrosion results in the loss of mechanical strength and reduction of the towers ability to support its own weight, the weight of conductors, ice and wind loads and other emergency loadings. The corrosion survey involves the inspection of steel tower legs both above and below groundline. This report deals exclusively with the assessment of corrosion of grillage footings below groundline.

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Visual examination of the grillage footing is the most direct method of assessing the degree of metal corrosion. However, this method is also very time consuming and expensive since it requires deep excavations (6 to 7 ft) in occasionally very stiff soils to perform a full inspection. In an attempt to optimize the inspection technique, Ontario Hydro's corrosion survey consists of measuring leg-to-soil potentials as an indirect method of assessing the degree of corrosion, supplemented by occasional shallow excavations for visual examinations.

One of the objectives of the present study is to gain experience with the Tower Leg Integrity Monitor and evaluate its usefulness in assessing steel corrosion on grillage footings. The TLIM 100 is an electrical instrument manufactured by Cormon Ltd in England and makes use of an electrochemical technique developed by CEGB which helps measure the open circuit corrosion current, I_{CORR} , associated with corrosion of transmission tower footings. In support of the Transmission Line Refurbishment Program undertaken by the task group/1/, several transmission lines were selected for detailed corrosion survey work involving electrical measurements with the TLIM-100, shallow excavations and collection of soil samples. The lines were chosen on the basis of their age (60 to 70 years old), location, soil conditions and knowledge of existing or past corrosion activity.

Presented in this preliminary report are the corrosion survey results obtained from a line section along circuit L22H, which is a 230 kV transmission line put into service in October 1958, in Eastern Region.

2.0 SURVEY METHODOLOGY

2.1 Circuit L22H

This section of 230 kV transmission line runs west to east from Hinchinbrook SS to Raisin River Jct just north of R.H. Saunders GS in Eastern Region. The selection of this line for a corrosion survey was based on the following factors:

- 1) Several sections of this line were surveyed in the summers of 1977, 1978 and 1980. The leg-to-soil potential measurements were available for comparison from the Eastern Region corrosion files.
- 2) No gas or oil pipelines run parallel to the line, therefore interferences from stray currents would be absent.
- 3) The line crosses several different soil types and conditions including swampy areas, till plains, lacustrine clay plains and sand plains. This type of survey would help identify the influence of soil type on measurements of corrosion current.

The section of L22H surveyed stretches from Easton-Yule Jct to Osnabruck Centre Rd which covers an approximate distance of 32 kms. Due to the preliminary nature of this study, the actual towers inspected were mostly those adjacent to concession roads which intersected the tower line. In this manner, a total of 32 towers were examined.

2.2 Testing Procedure

At each tower location, corrosion potential and corrosion current measurements were made for each footing using the Tower Leg Integrity Monitor. This procedure was followed to ensure that the localized corrosion present on any one of the footings would be detected. Disturbed soil samples were also collected from a depth of 30 to 60 cm (1 to 2 ft) from each tower location. These samples were later used for laboratory testing.

At selected tower locations, shallow excavations (60 to 90 cm) were dug for visual examination of near-surface steel corrosion.

During previous corrosion surveys, sacrificial anodes were installed in the ground at tower sites where corrosion activity was determined to be high, ie swampy areas. When these magnesium anodes were found at the tower locations for this study, a clip-on ammeter was used to measure the current passing through the connecting wire between the tower leg and the anodes. The current value indicates if the anode is protecting the footing steel, and also how long it will last at the present rate of consumption.

In the laboratory, the following tests were performed on the collected soil samples: moisture content, grain size distribution, electrical resistivity, pH and presence of sulphur. These soil parameters help to classify a soil in terms of its corrosivity/2/.

The presence of sulphur was determined by mixing a small quantity of soil with 15% HCl in a test tube. After a 30 second equilibration time, a lead acetate strip was inserted into the test tube. In the presence of sulphur (H_2S) the strip changes colour from white to brown. The presence of sulphur identifies the presence of sulphate-reducing bacteria which acts as a catalyst in the corrosion process.

The pH measurement was made by immersing a standard pH electrode into a 5:1 slurry of water and soil (125 mL/:50g).

Electrical resistivity was measured using a hand crank operated resistivity meter (Megger) and a standard size Miller soil box. The procedure followed for the laboratory measurement is outlined in ASTM G57. This method provides a "worst case" value since the soil is fully saturated before its resistivity measurement.

3.0 RESULTS

3.1 Potential and Current Readings with the TLIM

The potential and current readings made during this survey are tabulated in Table I. The tower numbers start at 50 near Osnabruck Centre Rd and increase westward toward Easton-Yule Jct. Figure 1a indicates the fluctuation of corrosion potential along the section of line surveyed. In general, the measured potentials are between -0.8 and -0.9 volts up to towers 190 to 200. Further west, the potentials are in general between -0.6 and -0.7 volts. The potentials measured at -1.4 volts near the eastern edge of the line, represent tower footings that have been cathodically protected with magnesium anodes.

These towers are located in swamps which is a condition known to promote greater corrosion.

Based on the experience obtained by Ontario Hydro in gathering tower leg-to-soil potentials, values more negative than -0.8 volts represent tower legs where the galvanizing is still acting as a protective coating. Potential values between -0.6 and -0.7 volts represent tower legs where the galvanizing has been removed allowing direct corrosion of the steel. Potential values between -0.4 and -0.5 volts indicate that corrosion has taken place. Based on the above criteria, most of the footings along the surveyed line are in good condition. A total of 7 footings out of 32 showed potential values less negative than -0.7 volts and therefore could require additional inspection.

Figure 2a shows the changes in corrosion current readings as measured by the TLIM. The majority of values are at or below 0.03 mA with a second grouping between 0.06 and 0.08 mA. Interpretation of these current values, as discussed in the TLIM manual, require plotting a frequency histogram of the data as shown in Figure 2b. Current values plotting on the extreme right hand side of the distribution correspond to the tower footings which definitely require a thorough visual examination. Based on this criterion, towers 94 and 151 should be inspected for corrosion activity. The corrosion current associated with tower 247 is significantly above background as shown in Figure 2a, and should therefore be inspected as well.

3.2 Magnesium Anode Current Readings

Current readings were made using a clip-on ammeter on the conductor wire connecting the tower leg to the sacrificial anode. These readings are tabulated in Table II. In most cases, one anode is connected to each footing of the transmission tower. The leg to soil potentials associated with each of the anodes are still very negative, indicating that the footing steel is still polarized.

The life span of a sacrificial anode is inversely related to the current flowing through the system. This life expectancy is calculated using the following equation/3/:

$$\text{Life (yrs)} = \frac{K \times \text{anode weight (lbs)} \times \text{efficiency} \times \text{utilization}}{\text{current in amperes}} \quad (1)$$

where initial anode weight = 17 lbs

efficiency = 50%

utilization = 85%

K = 0.116, constant based on the electrochemical equivalent for magnesium (1.2×10^{-4} g/coulomb)

An efficiency of 50% for magnesium anodes indicates that only half of the anode's weight is actually consumed in protection while the other half is lost to simple corrosion. A utilization of 85% implies that the anode will be replaced when 15% of its weight remains. The maximum current in Table II is 25.5 mA associated with tower 101. Assuming that this current is constant throughout the life of the anode,

$$\text{Life span} = \frac{0.116 \times 17 \times 0.5 \times 0.85}{0.025} = 33.5 \text{ years}$$

Since the anodes were placed in 1980, the minimum remaining life span is approximately 25 years. This life span estimate may be in error since the total anode current output may have decreased/3/ from the time of installation.

3.3 Soil Testing and Evaluation

The results of the moisture content, pH, resistivity and sulphur tests are tabulated in Table I. Of these four parameters, the dominant one is soil resistivity especially when it is in the low range ie, less than 5000 ohm-cms. The laboratory soil resistivities are plotted in Figures 3a and 3b. Figure 3b indicates that the frequency distribution of soil resistivities along the tower line is bimodal. Two major peaks occur between 1000 and 2000 ohm-cms and between 4000 and 6000 ohm-cms, reflecting the changes in soil type across the region. Figure 3a identifies a region of low soil resistivities between towers 110 and 150 followed by gradually increasing resistivities toward the west.

Since soil resistivity is associated with soil type, a plot of grain size distribution trends should mimic trends in soil resistivity. Figure 4 is a stacked bar graph illustrating soil grain size analysis results for selected towers along the L22H transmission line. At towers 116, 136 and 151, the soils exhibit a higher percentage of clay and silt-sized particles. Beyond towers 151, the per cent of sand in the soils increases significantly. The correlation between increasing soil resistivity and increasing percentages of sand-sized particles is confirmed in Figure 5.

The trend in grain size distribution was predicted prior to the survey by examining the physiography map of southern Ontario/4/. At Osnabrook Centre Rd, the physiographic region is known as the Glengarry till plain. Towards the west, the physiographic region changes to the Winchester clay plain (tower 136) followed by the Edwardsburg sand plain (tower 173) and finally the Smith Falls limestone plain (239) with its thin and heterogeneous soil cover.

Before identifying areas of potentially high corrosion activity, the remaining soil parameters must be taken into account. A rating system for these parameters has been published by Environment Canada (Table III), and was developed for evaluating corrosive soils for buried storage tanks. The soil aggressiveness value (S.A.V.) can also be calculated for this footing corrosion survey, however, since only one soil sample was collected per tower, the points associated with differential characteristics of resistivity and pH must be excluded/2/.

The modified S.A.V. values are plotted in Figure 6 and identify two areas of potentially higher corrosion activity. Between towers 70 and 90, the soil conditions are swampy which promotes slightly acidic pH's and higher concentrations of sulphate-reducing bacteria. Between towers 120 and 160, the soils are all of lower resistivities facilitating current flow in the corrosion cells.

3.3.1 Comments

The use of soil parameters alone in evaluating corrosive environments can be very misleading. It has been pointed out by several authors/5,6/, that the factors which are most influential in promoting corrosion are the degree of disturbance of the sediment and the heterogeneity of the environment. Differential aeration is a product of the above factors and will play a role in corrosion of underground structures located in zones of ground water table fluctuations and/or in zones of abruptly changing soil characteristics.

Geological and hydrological factors may influence where excessive corrosion will occur on a grillage footing. In fine-grained soils where the water table tends to fluctuate near the ground surface, corrosion may take place along the footing leg within a depth of 60 to 90 cm. In granular soils, or where the water table is deeper, corrosion may concentrate near the top of the grillage pad, 180 to 210 cm below ground surface. When different soil types are used in backfilling the grillage footing, corrosion may occur at the boundary between the soil types. This situation may occur when fine-grained backfill soil is partially replaced with coarser-grained soil. Also, when the backfill soil is not compacted to the in situ soil density, the contrast in void ratios may create a situation of differential aeration promoting corrosion at the grillage pad.

This discussion, although hypothetical in nature, points out that site specific ground water conditions and construction techniques should be taken into account, along with soil parameters, when accessing corrosion conditions.

3.4 Comparison to Past Potential Measurements

A routine corrosion survey was conducted along circuit L22H by Eastern Region personnel in 1978. The leg-to-soil potentials for 1978 are tabulated in Table I along with potential measurements made during this study. These measurements may not be directly comparable since it is not known whether the 1978 potentials are averages of readings from all 4 footings or not. In many cases, the 1988 potentials are more negative than the 1978 potentials, which may demonstrate the error produced by comparing the two values.

In the case of Towers 53, 116 and 145, the leg-to-soil potentials have become less negative by 0.15, 0.14 and 0.08 volts respectively. However, the associated corrosion currents of 0.0045, 0.0045 and 0.02 mA respectively do not identify unusually high corrosion activity. This implies that leg-to-soil potentials by themselves may be misleading when assessing corrosion activity.

4.0 CONCLUSIONS

Operation of the Tower Leg Integrity Monitor (TLIM) has proven to be very straight forward requiring only a few hours of training. One person can easily take the potential and current measurements for each tower leg in a matter of 1 to 2 minutes. The most time consuming aspect of the corrosion survey is travelling to the tower in question and clearing any brush which may be covering the tower legs. Taking measurements on only one of the four tower legs would not accelerate the survey significantly. If below grade visual

inspections and soil sampling are to be done, a minimum of one extra person is required for the survey.

The measurement of corrosion current, associated with corrosion cells along the grillage footing, may be strongly influenced by stray currents originating from pipeline rectifiers, or other direct current operations ie, subways, railroads. The rectifiers are used in impressed current cathodic protection schemes for oil and gas pipelines. Stray currents from such systems may be picked up at a nearby transmission tower leg, travel along the connecting skywire, and discharge at a tower further down the line. At this point of discharge, corrosion of the steel footing will be accelerated and the measured corrosion current will be anomalously high.

The measurement of corrosion current may also be greatly influenced by seasonal moisture changes. The TLIM manual recommends that measurements be made during periods of highest moisture content ie, spring or fall. Local geological and hydrogeological conditions will influence the magnitude of soil moisture fluctuations.

The influence of stray currents and seasonal moisture changes on the corrosion current will be further investigated by future corrosion surveys.

Leg-to-soil potential measurements have been the basis of Ontario Hydro's corrosion surveys to date. Some degree of corrosion activity is indicated by potentials at or more positive than -0.6 volts. There should be then some correlation between potential measurements and corrosion current measurements. Large currents should be related to more positive potentials and small currents to more negative potentials. These two values are plotted in Figure 7, each point representing one tower. Although the database is very limited at this time a few comments can be made. Potentials between -0.6 and -0.7 volts are not associated with higher corrosion current values. In one case (tower 151), a high corrosion current is associated with a leg-to-soil potential of -0.87 volts which would indicate that the tower leg is still protected by the galvanizing. These few measurements indicate that potential readings coupled with current readings would provide a better basis for evaluating the presence and degree of corrosion activity.

Figure 8 is a plot of corrosion current versus the modified S.A.V. which is a parameter determined exclusively from laboratory measurements on collected soil samples. Although there appears to be a rough trend of higher corrosion currents associated with higher S.A.V. values, the large scatter in the data confirms that soil parameters should only be used to supplement field measurements of corrosion potential and current.

The true value of the Tower Leg Integrity Monitor will only be determined when specific tower footings can be removed for corrosion inspection after the electrical measurements have been made. This activity is being planned for the near future along with additional corrosion surveys in various areas of the Province.

ACKNOWLEDGMENTS

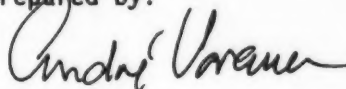
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Approved by:

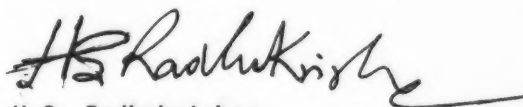


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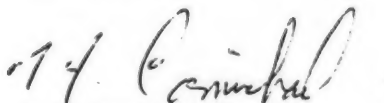


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TABLE I

Tower Line Footing Corrosion Survey
Eastern Region: Circuit L22H

Summary of Field and Laboratory Data

Tower No	Potential E (V)	Current I (mA)	Moisture %	pH	Soil Resistivity ρ (Ω -cm)	Sulphur	Modified S.A.V.	E(V) 1978
53	-0.616	0.0045	-	6.8	6 000	*	11	-0.77
58	-0.807	0.020	29.5	6.6	5 000		10	-0.7
71	-0.873	0.067	35.6	7.1	2 000	*	17	-0.78
74	-0.822	0.017	23.4	6.6	5 500		7	-0.76
76	-0.714	0.016	-	5.5	8 500	*	14	-0.78
77	-1.413	0.058	20.8	6.9	1 400	*	16	
83	-0.875	0.075	74.3	6.2	4 400		13	-0.81
93	-0.812	0.021	22.8	6.9	5 400	*	11	-0.82
94	-1.447	0.112	22.7	7.0	7 000	*	11	
98	-0.859	0.014	-	7.0	4 500		10	-0.84
99	-1.398	0.069	20.0	7.1	10 400	*	9	
100	-0.890	0.029	17.6	6.9	6 500	*	9	-0.8
101	-1.382	0.054	22.8	7.6	6 000	*	10	
114	-0.826	0.032	-	6.7	2 500		10	-0.81
116	-0.666	0.004	27.1	6.6	2 800		9	-0.81
121	-0.876	0.063	16.7	7.6	2 000	*	13	-0.78
129	-0.832	0.027	23.6	6.7	2 500	*	14	-0.8
136	-0.867	0.076	35.9	7.5	2 000		12	-0.84
145	-0.664	0.018	29.1	5.7	4 500		12	-0.74
151	-0.872	0.268	34.9	6.3	2 000		15	-0.81
158	-0.814	0.045	26.8	5.5	4 500		12	-0.79
173	-0.796	0.011	23.4	6.0	13 000		7	-0.8
182	-0.881	0.037	17.6	8.0	4 000	*	11	-0.8
190	-0.769	0.034	16.3	6.4	6 600		7	
196	-0.788	0.019	2.1	6.1	8 000		9	
200	-0.620	0.022	34.8	6.9	7 000		8	
201	-0.716	0.006	19.7	7.6	6 000		6	
219	-0.621	0.007	22.1	6.7	9 500		7	
231	-0.638	0.006	16.0	6.7	7 600		5	
239	-0.713	0.012	20.7	6.6	9 980		7	
247	-0.794	0.070	23.3	6.9	14 600	*	9	
262	-0.652	0.008	18.2	7.2	5 000	*	12	

*presence of sulphur

S.A.V. = soil aggressiveness value
 Ω -m = Ω -cm/100

TABLE II

Current Measurements from
Magnesium Anodes (mA)

<u>Tower</u>	<u>Footing 1</u>	<u>Footing 2</u>	<u>Footing 3</u>	<u>Footing 4</u>	<u>Installation Date</u>
77	7 (-2.350)	6.5 (-1.369)	7.5 (-1.442)	8.2 (-1.492)	(7/80)
94	25 (-1.514)	25.5 (-1.364)	19.9 (-1.446)	19.0 (-1.465)	(6/80)
99	22.5 (-1.366)	20.0 (-1.342)			(6/80)
101	17.2 (1.380)	19.5 (1.348)	25.5 (-1.42)	16 (-1.378)	(6/80)

NOTE: Values in brackets are the associated potentials measured in volts.

TABLE III

BASIS FOR THE EVALUATION OF UNDERGROUND ENVIRONMENTS
(S.A.V. SYSTEMS)

I BASIC CHARACTERISTICS		POINTS
• Soil Resistivity	< 300	12
	300 - 1,000	10
	1,000 - 2,000	8
	2,000 - 5,000	6
	5,000 - 10,000	3
	10,000 - 25,000	1
	> 25,000	0
• Soil pH	< 3	8
	3 - 5	6
	5 - 6.5	4
	6.5 - 7.5	2
	7.5 - 9	1
	> 9	0
• Soil Moisture	Saturated	3
	Damp	2
	Dry	0
II DIFFERENTIAL CHARACTERISTICS		
• Resistivity (ratio of extremes)	> 1:10	3
	> 1: 5	2
	> 1: 3	1
	< 1: 3	0
Soil pH (Difference in pH Value)	3	2
	1.5 - 3	1
	0 - 1.5	0
III SULFIDES		
Positive		4
Negative		0

TOWERLINE FOOTING CORROSION SURVEY

Eastern Region : Circuit L22H

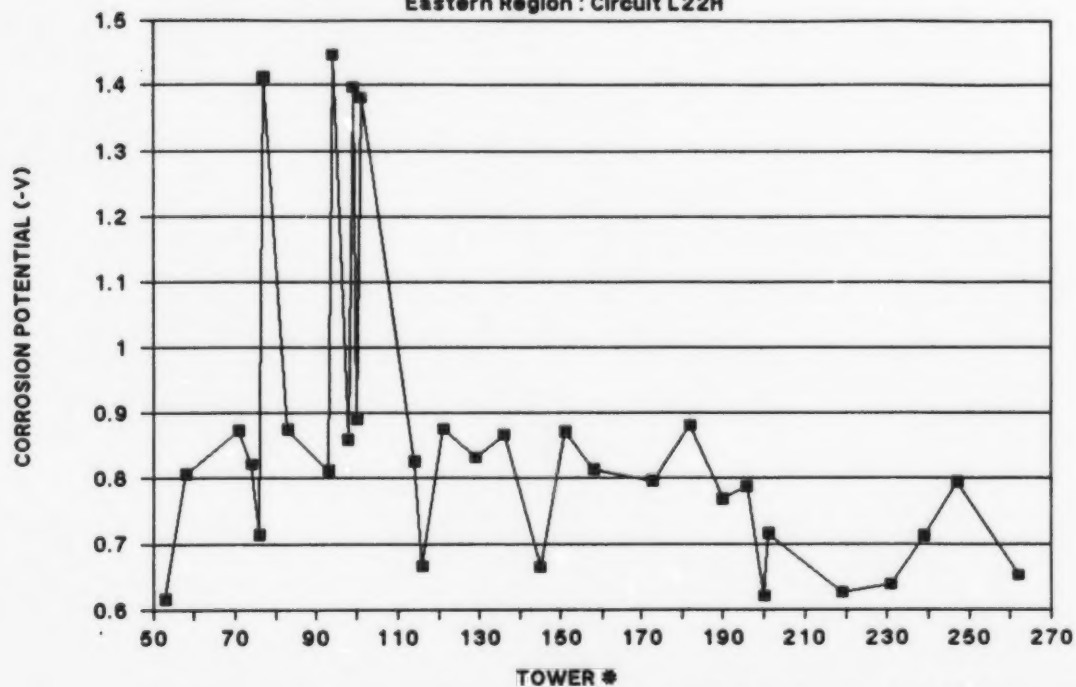


Figure 1a: Corrosion potential profile along cct L22H

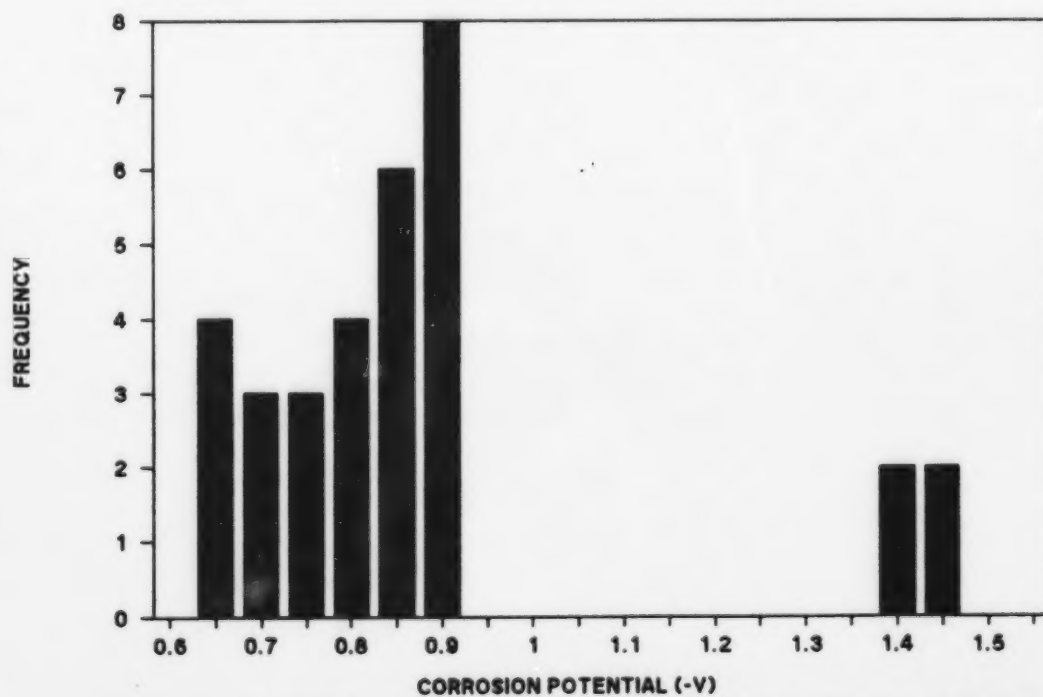


Figure 1b: Histogram of corrosion potentials for cct L22H

TOWERLINE FOOTING CORROSION SURVEY

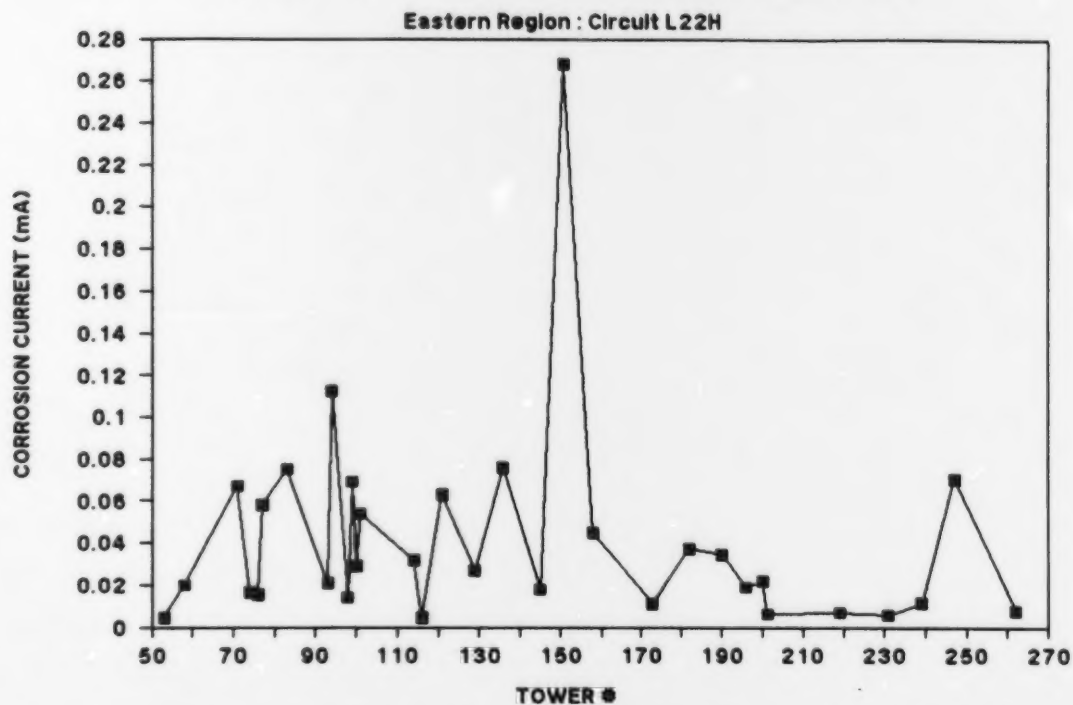


Figure 2a: Corrosion current profile along cct L22H

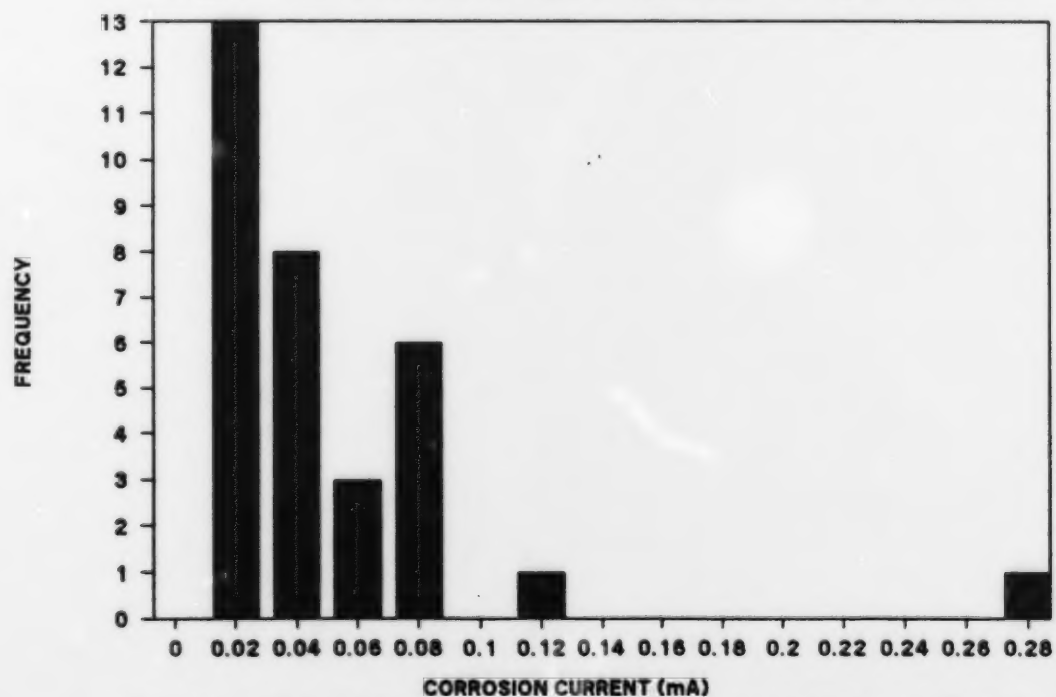


Figure 2b: Histogram of corrosion currents for cct L22H

TOWERLINE FOOTING CORROSION SURVEY

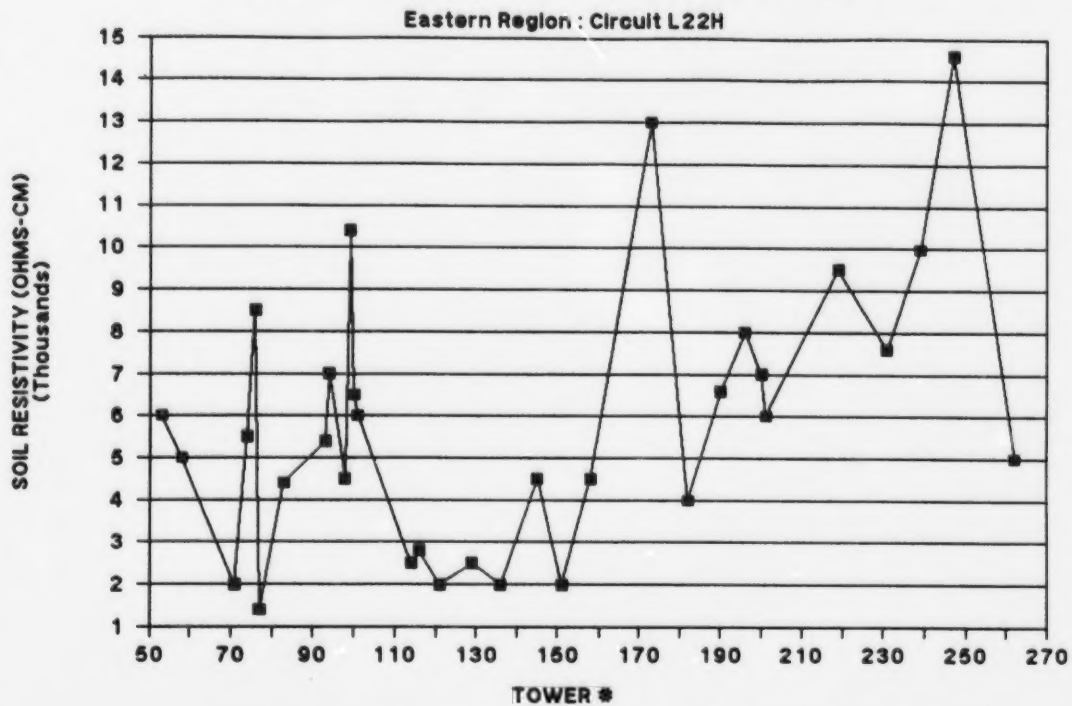


Figure 3a: Soil resistivity profile along cct L22H

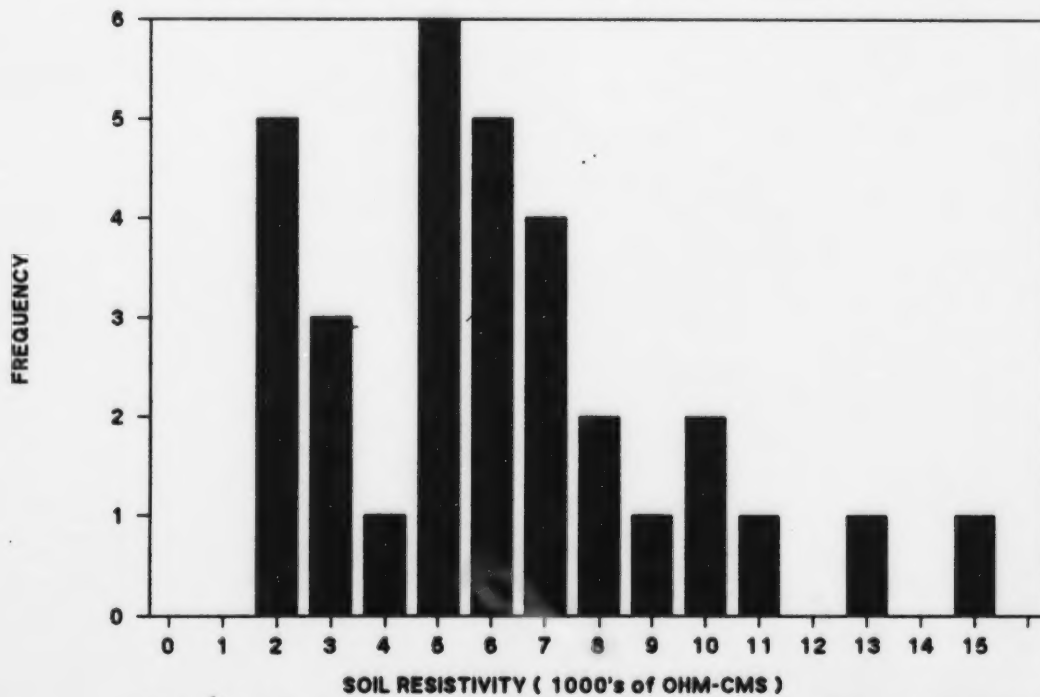


Figure 3b: Histogram of soil resistivities for cct L22H

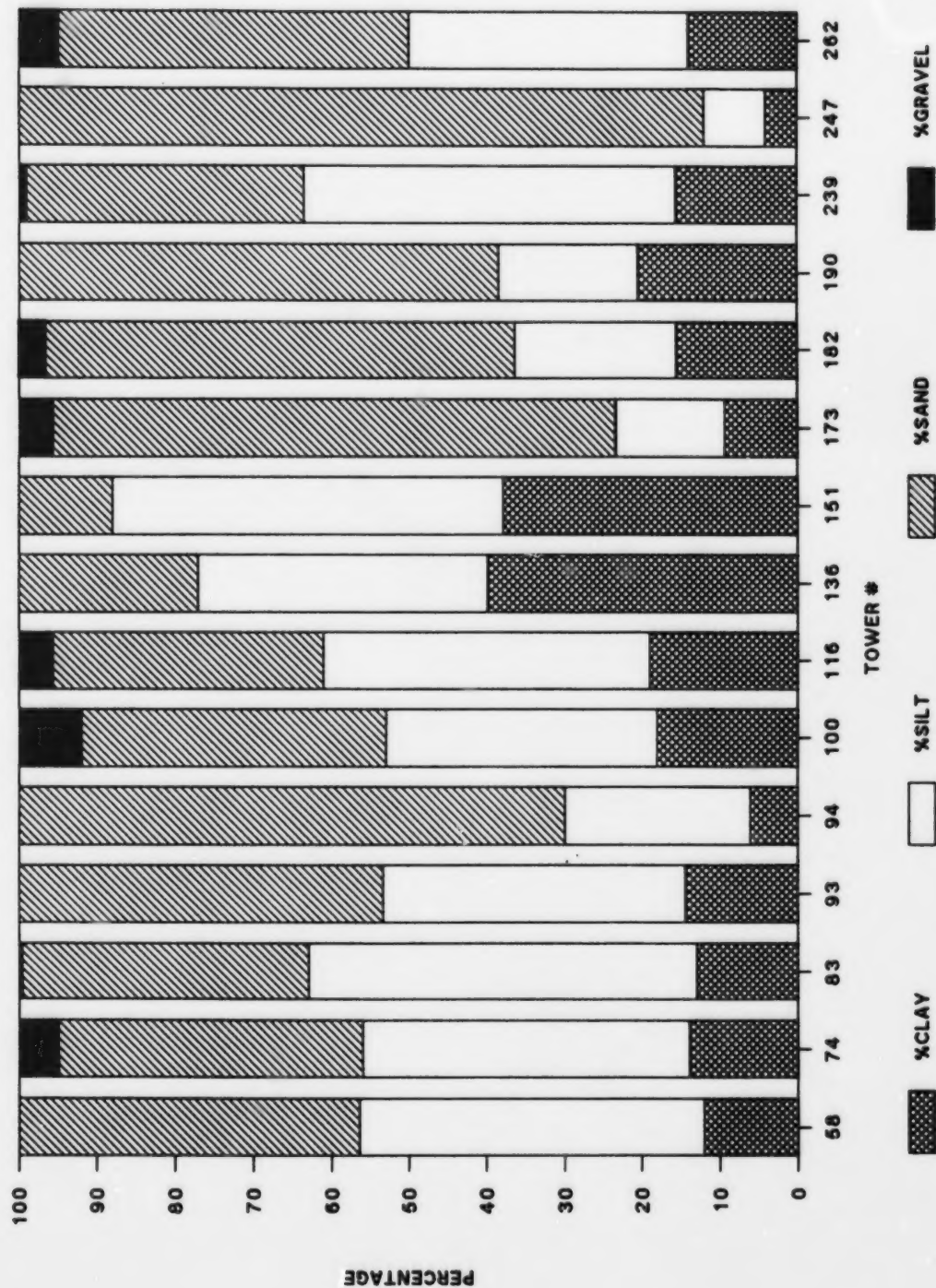


Figure 4: Particle size analysis for certain soils along cct L22H in Eastern Region

SOIL RESISTIVITY CORRELATION

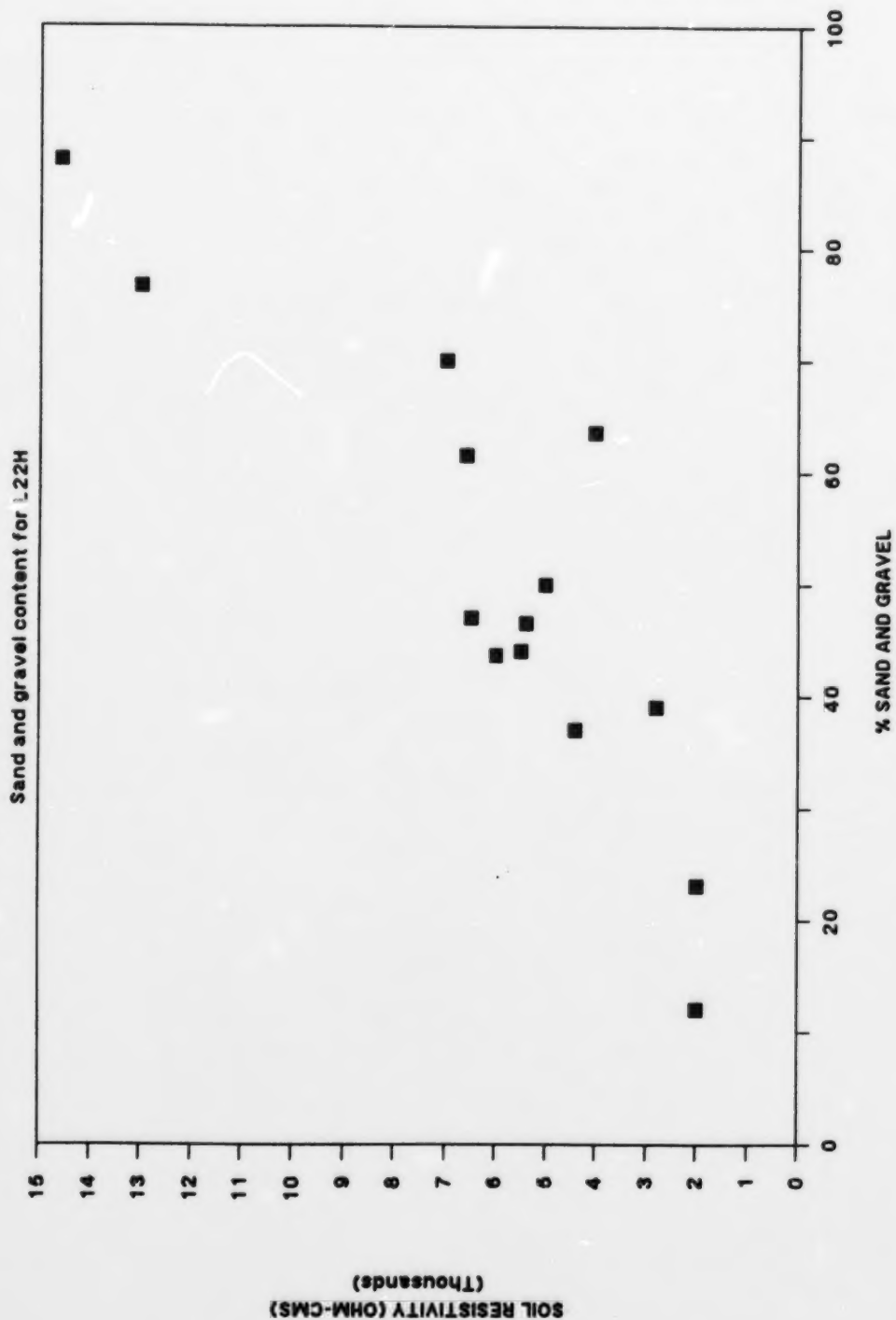


Figure 5

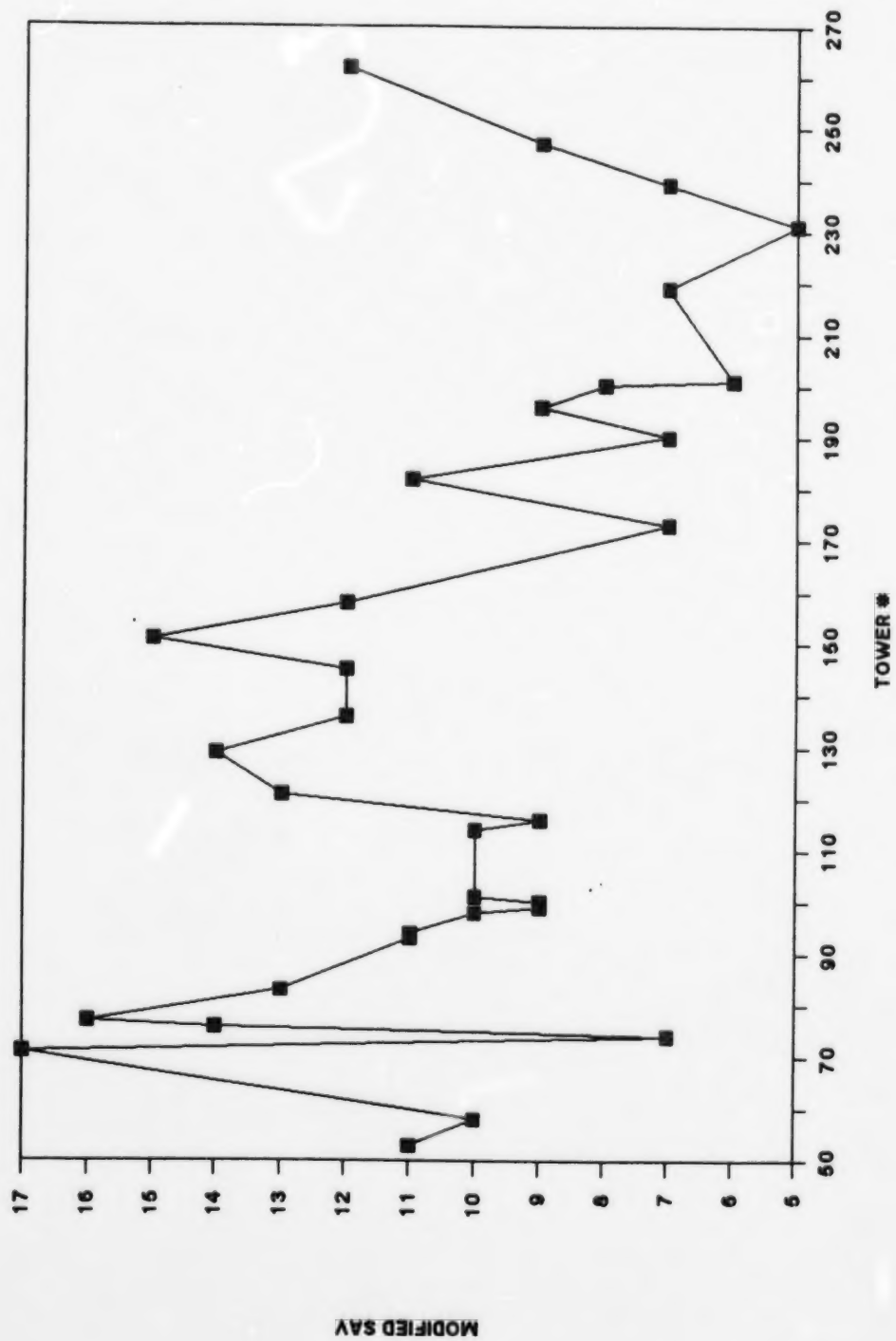


Figure 6: Soil Aggressiveness Value profile for cct L22H

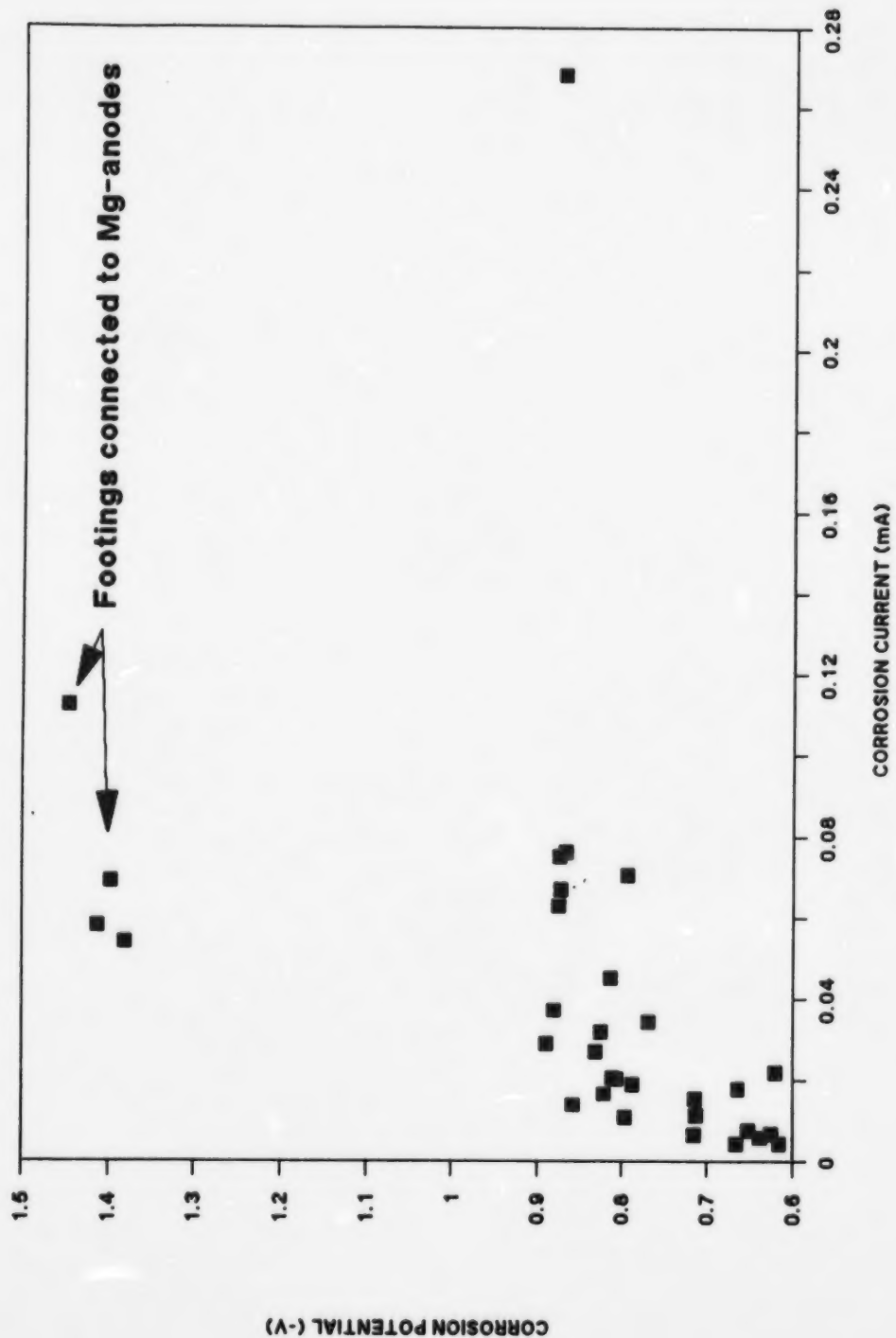


Figure 7: Corrosion potential - corrosion current correlation

